CLAIMS

What is claimed is:

1. A method of recording at least two multiplexed holograms comprising the steps of

reflecting either an object beam or a reference beam from at least one portion of a first aspherical reflecting surface, the object beam and the reference beam generated by a coherent light source, thereby causing the object beam and the reference beam to intersect and form an interference pattern at a plane defined by the intersection of said object and reference beams at a selected storage location in a recording media, thereby recording a first hologram at said selected storage location; and

rotating at least one of a portion of the reference beam impinging on a recording media at the selected storage location and a portion of the object beam impinging on the recording media at said selected storage location through a selected azimuthal angle about an axis that lies in the plane formed by optical axes of said portions of the object beam and the reference beam impinging on the recording media,

wherein said axis passes through a plane defined by the intersection of the object beam and the reference beam in the recording media, and

wherein an angle between optical paths of said portions of the object beam and the reference beam impinging on the recording media is preserved,

thereby recording at least two azimuthally multiplexed holograms.

2. The method of Claim 1 further including a step of rotating at least one of the portion of the reference beam impinging on the recording media at a selected storage location or the portion of the object beam impinging on the recording media at a selected storage location or combinations thereof through a selected planar angle about an axis that is perpendicular to the plane formed by the optical axis of said portions of the object beam and the reference beam impinging on the recording media,

wherein said axis passes through a plane defined by the intersection of the object beam and the reference beam in the recording media, and

thereby recording at least two planar-angle multiplexed holograms.

3. The method of Claim 2 wherein a plurality of azimuthally multiplexed and planar-angle angularly multiplexed holograms is recorded. %

4. The method of Claim 3 wherein the reference beam is reflected from the at least one portion of an aspherical reflecting surface.

5. The method of Claim 4 wherein the at least one portion of the aspherical reflecting surface is a portion of an ellipsoidal reflecting surface .

6. The method of Claim 4 wherein the aspherical reflecting surface is a segmented surface comprising a group of planar mirrors.

7. The method of Claim 5 further including the steps of

directing the reference beam to said ellipsoidal reflecting surface by reflecting the reference beam from at least one additional reflecting surface.

8. The method of Claim 7 further including the step of

at least partially rotating either one or both the portion of the ellipsoidal reflecting surface and the additional reflecting surface through a series of selected angles, about a first axis, thereby rotating the portion of the reference beam impinging on the recording media at the selected storage location with respect to an axis formed by the optical axis of the portion of the object beam impinging on the recording media at said storage location through a series of azimuthal multiplexing angles $\{\varphi_j\}$, wherein j is an integer, while preserving the

angle between said portions the object beam and the reference beam impinging on the recording media at said storage location.

9. The method of Claim 8 further including the step of

at least partially rotating either one or both the portion of the ellipsoidal reflecting surface and the additional reflecting surface through a series of selected angles about a second axis, perpendicular to the first axis, thereby changing an angle between the portions of the object beam and the reference beam impinging onto the selected storage location in a recording media through a series of planar multiplexing angles $\{\theta_i\}$, wherein i is an integer.

10. The method of Claim 7 further including the steps of:

at least partially rotating either one or both the portion of the ellipsoidal reflecting surface and the additional reflecting surface through a series of selected angles with respect to a first axis, thereby changing an angle between the portions of the object beam and the reference beam impinging onto a recording media at the selected storage location through a series of planar multiplexing angles $\{\theta_i\}$, wherein i is an integer; and

for each selected planar multiplexing angle θ_i, at least partially rotating either one or both the portion of the ellipsoidal reflecting surface and the additional reflecting surface through a series of selected angles, about a second axis, perpendicular to the first axis, thereby rotating the portion of the reference beam impinging on the recording media at the selected storage location about an axis formed by the optical axis of the portion of the object beam impinging on the recording media at said storage location through a series of azimuthal multiplexing angles $\{\varphi_j\}$, wherein j is an integer, while preserving the angle between said portions the object beam and the reference beam impinging on the recording media at said storage location.

11. The method of Claim 10 wherein the additional reflecting surface is at least partially rotated with respect to the first and the second axes.

12. The method of Claim 11 wherein the additional reflecting surface is a planar mirror.

13. method of Claim 11 wherein the additional reflecting surface is a curved reflecting surface.

14. The method of Claim 11 wherein the additional reflecting surface is an aspherical surface

15. The method of Claim 11 wherein said additional reflecting surface and the recording media are disposed on the same side of any plane that is (a) parallel to a surface of the recording media and (b) intersects the ellipsoidal reflecting surface.

16. The method of Claim 15 wherein a portion of the reference beam impinging on the additional reflecting surface is coaxial with an axis formed by the two foci of the ellipsoidal reflecting surface.

17. The method of Claim 15 wherein a portion of the reference beam impinging on the additional reflecting surface is not coaxial with an axis formed by the two foci of the ellipsoidal reflecting surface.

18. The method of Claim 11 wherein said additional reflecting surface and the recording media are disposed on different sides of any plane that is (a) parallel to the surface of a recording media and (b) intersects the ellipsoidal reflecting surface.

19. The method of Claim 11 wherein directing the reference beam further includes:

directing the reference beam reflected from the additional reflecting surface to a second additional reflecting surface; and

reflecting the reference beam from said second additional reflecting surface.

20. The method of Claim 11 wherein directing the reference beam further includes:

directing the reference beam reflected from the ellipsoidal reflecting surface to a second aspherical reflecting surface; and

reflecting said reference beam from the second aspherical reflecting surface.

21. A method of recording azimuthally multiplexed holograms in an optical recording media, comprising the steps of:

(a) predetermining a series of azimuthal multiplexing angles $\{\varphi_j\}$, wherein *j* is an integer;

(b) selecting an angle φ_a wherein *a* is an integer and φ_a is selected from the series $\{\varphi_j\}$;

(c) directing an object beam and a reference beam that are mutually coherent at a selected data storage location situated along a selected track on the optical recording media,

wherein the reference beam is reflected from at least one portion of an aspherical mirror, and

wherein a portion of the reference beam impinging onto the recording media has an azimuthal angle φ_a with respect to an axis formed by an optical axis of a portion of the object beam impinging onto the recording media;

(d) repeating step (c) for a plurality of selected data storage locations, thereby recording a plurality of holograms, each at a selected storage location along the selected track on the optical recording media; and

(e) repeating steps (c) through (d) for a different integer *a*, wherein the subsequent holograms are recorded in the selected track using the storage locations utilized by the previously recorded plurality of holograms.

22. The method of Claim 21 further including repeating steps (a) through (e), wherein a different track on the optical recording media is selected.

23. The method of Claim 21 wherein the data storage locations along a track are non-overlapping and substantially abutting.

24. The method of Claim 21 wherein the optical recording media is a disk or card.

25. The method of Claim 21 wherein the at least one portion of the aspherical mirror is a portion of an ellipsoidal mirror.

26. The method of Claim 21 further including a step of reflecting the reference beam from at least one additional reflecting surface.

27. A method of recording azimuthally and angularly multiplexed holograms on an optical recording media, comprising the steps of:

(a) predetermining a series of planar multiplexing angles $\{\theta_i\}$, wherein i is an integer;

(b) predetermining a series of azimuthal multiplexing angles $\{\varphi_j\}$, wherein j is an integer;

(c) selecting a pair of angles (θ_a,φ_b) wherein a and b are integers and θ_a and φ_b are independently selected from the series $\{\theta_i\}$ and $\{\varphi_j\}$, respectively;

(d) directing an object beam and a reference beam that are mutually coherent at a data storage location situated along a selected track on the optical recording media,

wherein the reference beam is reflected from at least one portion of an aspherical mirror, and

wherein an angle between portions of the object beam and the reference beam impinging onto a recording media is θ_a, and

wherein the portion of the reference beam impinging onto the recording media has an azimuthal angle φ_b with respect to an axis formed by an optical axis of a portion of the object beam impinging onto the recording media.

28. The method of Claim 27 further including the steps of:

(e) repeating step (d) for a plurality of data storage locations along a selected track, thereby recording a plurality of holograms, each at a storage location along the selected track on the optical recording media; and

(f) repeating steps (c) through (e) for different integers *a* and *b*, wherein the subsequent holograms are recorded along the selected track using the storage location utilized by the previously recorded plurality holograms.

29. The method of Claim 27 further including the steps of:

(e) repeating step (d) for different integers *a* and *b* for the same storage location on a selected track thereby recording a plurality of holograms, each at the same storage location along the selected track on the optical recording media;

(f) repeating steps (c) through (e) for different storage locations along the selected track.

30. The method of Claim 27 further including repeating steps (a) through (f), wherein a different track on the optical recording media is selected.

31. The method of Claim 27 wherein the data storage locations along a track are non-overlapping and substantially abutting.

32. The method of Claim 27 wherein the optical recording media is a disk or card.

33. The method of Claim 27 wherein the at least one portion of the aspherical mirror is a portion of an ellipsoidal mirror.

34. The method of Claim 27 further including a step of reflecting the reference beam from at least one additional reflecting surface.

35. The method of Claim 34 wherein the additional reflecting surface is at least partially rotatable with respect to a first axis and, independently, a second axes.

36. The method of Claim 35 further including the steps of:

at least partially rotating the additional reflecting surface through a series of selected angles about the first axis, thereby changing an angle between the portion of the object beam and the portion of the reference beam impinging onto a recording media through the series of planar multiplexing angles $\{\theta_i\}$; and

at least partially rotating the additional reflecting surface through a series of selected angles about the second axis perpendicular to the first axis, thereby rotating the portion of the reference beam impinging on the recording media through the series of azimuthal multiplexing angles $\{\varphi_j\}$with respect to the axis formed by an optical axis of the portion of the object beam impinging on the recording media, while preserving the angle between said portions the object beam and the reference beam impinging on the recording media.

37. The method of Claim 35 wherein the additional reflecting surface is at least partially rotated with respect to the first and the second axes.

38. The method of Claim 37 wherein the additional reflecting surface is a planar mirror.

39 method of Claim 37 wherein the additional reflecting surface is a curved reflecting surface.

40. The method of Claim 37 wherein the additional reflecting surface is an aspherical surface

41. The method of Claim 36 wherein said additional reflecting surface and the recording media are disposed on the same side of any plane that is (a) parallel to a surface of the recording media and (b) intersects the ellipsoidal reflecting surface.

42. The method of Claim 41 wherein a portion of the reference beam impinging on the additional reflecting surface is coaxial with an axis formed by the two foci of the ellipsoidal reflecting surface.

43. The method of Claim 41 wherein a portion of the reference beam impinging on the additional reflecting surface is not coaxial with an axis formed by the two foci of the ellipsoidal reflecting surface.

44. The method of Claim 36 wherein said additional reflecting surface and the recording media are disposed on different sides of any plane that is (a) parallel to a surface of the recording media and (b) intersects the ellipsoidal reflecting surface.

45. The method of Claim 36 wherein the step of directing the reference beam further includes:

directing the reference beam reflected from the additional reflecting surface to a second additional reflecting surface; and

reflecting the reference beam from said second additional reflecting surface.

46. The method of Claim 36 wherein the step of directing the reference beam further includes:

directing the reference beam reflected from the ellipsoidal reflecting surface to a second aspherical reflecting surface; and

reflecting said reference beam from the second aspherical reflecting surface.

47. A method of reading azimuthally and angularly multiplexed holograms recorded in an optical recording media, comprising the steps of:

(a) predetermining at least one selected multiplexed hologram of a selected storage location along a selected track of recorded storage locations in an optical recording media;

(b) predetermining at least one of a plurality of azimuthal multiplexing angles $\{\varphi_j\}$, wherein j is an integer, used to record said selected multiplexed hologram;

(c) selecting a φ_a wherein a is an integer φ_a is selected from the series $\{\varphi_j\}$;

(d) directing a reference beam at the selected data storage location,

wherein the reference beam is reflected from at least one portion of an aspherical mirror, and

wherein the portion of the reference beam impinging onto the recording media has an azimuthal angle φ_a with respect to an axis formed by the optical axis of the object beam used to record said selected multiplexed hologram, and

wherein reconstructing of the selected multiplexed hologram includes relaying a diffraction pattern from the multiplexed hologram with reconstruction optics to a detector; and

(e) repeating step (d) for a plurality of selected multiplexed holograms previously recorded in data storage locations along at least one selected track for different integer a as may be necessary to read other selected multiplexed holograms, thereby reading a plurality of selected multiplexed holograms, each at a selected storage location along a track on the optical recording media.

48. A method of reading azimuthally and angularly multiplexed holograms recorded in an optical recording media, comprising the steps of:

(a) predetermining at least one selected multiplexed hologram of a selected storage location along a selected track of recorded storage locations in an optical recording media;

(b) predetermining at least one of a plurality of planar multiplexing angles $\{\theta_i\}$, wherein *i* is an integer, used to record said selected multiplexed hologram;

(c) predetermining at least one of a plurality of azimuthal multiplexing angles $\{\varphi_j\}$, wherein *j* is an integer, used to record said selected multiplexed hologram;

(d) selecting a pair of angles (θ_a,φ_b) wherein *a* and *b* are integers and θ_a and φ_b are selected from the series $\{\theta_i\}$ and $\{\varphi_j\}$, respectively;

(e) directing a reference beam at the selected data storage location,

wherein the reference beam is reflected from at least one portion of an aspherical mirror, and

wherein the angle between a portion of the reference beam impinging on a recording media at the selected storage location and a portion of the object beam impinging on the recording media at said selected storage location is θ_a, and

wherein the portion of the reference beam impinging onto the recording media has an azimuthal angle φ_b with respect to an axis formed by the optical axis of the object beam used to record said selected multiplexed hologram, and

wherein reconstructing of the selected multiplexed hologram includes relaying a diffraction pattern from the multiplexed hologram with reconstruction optics to a detector; and

(f) repeating step (e) for a plurality of selected multiplexed holograms previously recorded in data storage locations along at least one selected track for different integers *a* and *b* as may be necessary to read other selected multiplexed holograms, thereby reading a plurality of selected multiplexed holograms, each at a selected storage location along a track on the optical recording media.

49. An apparatus for recording holographically stored information comprising:

a recording media;

at least one portion of an aspherical reflecting surface;

at least one additional reflecting surface;

a motive device for rotating at least one of either at least one portion of the aspherical reflecting surface or the at least one additional reflecting surface about a first axis and, independently, a second axis, perpendicular to the first axis; and

means for directing an object beam and a reference beam that are mutually coherent along their respective optical paths,

wherein either an object beam or a reference beam is reflected from at least one portion of the aspherical reflecting surface to intersect and form an interference pattern with the other at a storage location in the recording media.

50. The apparatus of Claim 49 wherein at least one portion of the aspherical reflecting surface is a portion of an ellipsoidal reflecting surface.

51. The apparatus of Claim 50 wherein at least one additional reflecting surface can be independently rotated about the first and the second axes.

52. The apparatus of Claim 51 wherein the motive device for rotating the additional reflecting surface is a two-dimensional galvanometer.

53. The apparatus of Claim 51 wherein the motive device for rotating the additional reflecting surface is a MEMS device.

54. The apparatus of Claim 51 wherein the motive device for rotating the additional reflecting surface includes two independently controlled one-dimensional galvanometers.

55. The apparatus of Claim 51 wherein the motive device for rotating the additional reflecting surface is a one-dimensional galvanometer mounted on a rotary motive device

56. The apparatus of Claim 51 wherein

the first focus of the ellipsoidal reflecting surface is located on at least one additional reflecting surface; and

the second focus of the ellipsoidal reflecting surface is located on a surface of or within the recording media.

57. The apparatus of Claim 56 wherein

either the object beam or the reference beam is directed to the ellipsoidal reflecting surface by reflecting either the object beam or the reflecting beam from the additional reflecting surface, and

wherein said additional reflecting surface can be rotated about at least one axis to effect redirection of one of said object or reference beams through an azimuthal arc of at least about 45° on said ellipsoidal reflecting surface.

58. The apparatus of Claim 57 wherein said additional reflecting surface can be rotated about at least one axis to effect redirection of one of said object or reference beams through an azimuthal arc of at least 90° on said ellipsoidal reflecting surface.

59. The apparatus of Claim 57 wherein said additional reflecting surface can be rotated about at least one axis to effect redirection of one of said object or reference beams

through an azimuthal arc of at least 90° and less than or equal to 180° on said ellipsoidal reflecting surface.

60. The apparatus of Claim 57 wherein said additional reflecting surface can be rotated about at least one axis to effect redirection of one of said object or reference beams through an azimuthal arc of at least 90° and less than or equal to 270° on said ellipsoidal reflecting surface.

61. The apparatus of Claim 57 wherein said additional reflecting surface can be rotated about at least one axis to effect redirection of one of said object or reference beams through an azimuthal arc of at least about 90° and less than or equal to about 360° on said ellipsoidal reflecting surface.

62. The apparatus of Claim 57 wherein said additional reflecting surface can be rotated about at least one axis to effect redirection of one of said object or reference beams through an azimuthal arc of at least about 180° and less than or equal to about 360° on said ellipsoidal reflecting surface.

63. The apparatus of Claim 57 wherein the additional reflecting surface is a planar mirror.

64. The apparatus of Claim 57 wherein the additional reflecting surface is a curved reflecting surface.

65. The apparatus of Claim 57 wherein the additional reflecting surface is an aspherical surface

66. The apparatus of Claim 57 wherein said additional reflecting surface and the recording media are disposed on the same side of any plane that is (a) parallel to a surface of the recording media and (b) intersects the ellipsoidal reflecting surface.

67. The apparatus of Claim 66 wherein a portion of the reference beam impinging on the planar mirror is coaxial with an axis formed by the two foci of the ellipsoidal reflecting surface.

68. The apparatus of Claim 66 wherein a portion of the reference beam impinging on the planar mirror is not coaxial with an axis formed by the two foci of the ellipsoidal reflecting surface.

69. The apparatus of Claim 57 wherein said additional reflecting surface and the recording media are disposed on different sides of any plane that is (a) parallel to a surface of the recording media and (b) intersects the first ellipsoidal reflecting surface.

70. The apparatus of Claim 57 further including a second additional reflecting surface, wherein the reference beam reflected from the additional reflecting surface is directed to the second additional reflecting surface.

71. The apparatus of Claim 57 further including a second aspherical reflecting surface, wherein the reference beam reflected from the ellipsoidal reflecting surface is directed to the second aspherical reflecting surface.

72. An apparatus for reading and/or recording of holographically stored information comprising:

an optical recording media comprising information previously recorded as holograms;

at least one portion of an aspherical reflecting surface;

at least one additional reflecting surface;

reconstruction optics for reconstructing at least one selected hologram;

a detector for detecting the selected reconstructed hologram;

a motive device for rotating at least one of either at least one portion of the aspherical reflecting surface or the at least one additional reflecting surface about a first axis and, independently, a second axis, perpendicular to the first axis; and

a means for directing a reference beam along its optical path, wherein a reference beam is reflected from at least one portion of the aspherical reflecting surface to impinge on at least one selected storage location in the recording media.

73. The apparatus of Claim 72 wherein reconstructing the selected multiplexed hologram includes relaying a diffraction pattern from the selected multiplexed hologram with reconstruction optics to a detector.

74. The apparatus of Claim 72 further including means for directing an object beam and the reference beam that are mutually coherent along their respective optical paths.

75. The apparatus of Claim 74 wherein either the object beam or the reference beam is reflected from at least one portion of the aspherical reflecting surface to intersect and form an interference pattern with the other at a storage location in the recording media.

76. An information storage device comprising an optical recording media wherein

said media includes a plurality of tracks;

each track including a plurality of data storage locations;

each location storing a plurality of holographically recorded images, wherein holographically recorded images stored in each storage location are both planar-angle-multiplexed and/or azimuthally multiplexed, and

wherein the data storage locations are non-overlapping and substantially abutting.